- Mass transit and ride-share devices that eliminate the inconveniences of exact change requirements
- Traffic control measures that provide preferential treatment for high occupancy vehicles
- Planning activities for fleet operations that are enhanced by a wide range of data availability
- Fleet operations that are optimized by the application of real-time monitoring
- Fleet control techniques that are flexible and responsive to user demands
- Fleet monitoring information that integrates computer assisted dispatching, customer information and passenger security
- Electronic data communications for mass transit fleets (replacing voice communications)
- Automated vehicle controls

4.0 THE MOBILEVISION LMS SERVICES SOLUTION

4.1 MobileVision's Network IVHS Services

MobileVision believes it has an advantage providing IVHS services because of the LMS technology developed for its system. Vehicle location, ancillary data communications, and ancillary two-way voice communications are provided in a *single* radio unit solution. MobileVision's planned national 900 MHz network is designed specifically for providing cost-effective IVHS services, such as ATMS, ATIS, and CVO.

Set forth below are three of the IVHS functional areas and how MobileVision's network and services will meet these IVHS requirements.

4.1.1 Advanced Traffic Management Systems ("ATMS")

MobileVision's vehicle unit and Network provides the power of an on-board computer in the vehicle (e.g., a Smart Vehicle), and provides the wireless link to/from the local, regional and national street, highway and transportation departments computer databases. This creates the link for the Smart Highway, i.e., ATMS.

4.1.2 Advanced Traveler Information Systems ("ATIS")

The MobileVision LMS system can provide the location, data, and voice capability required by ATIS systems to acquire, analyze, communicate and present information to assist travelers, without integration into another system's products or without coverage "holes" in urban areas. Specific ATIS features and products include the following:

4.1.2.1 Navigation systems with electronic vehicle or traveler position determination. The MobileVision system satisfies this feature by means of its vehicle unit which transmits a spread spectrum location "burst". The position of the vehicle is determined by multilateration based upon the time differences in the arrival of the "burst" at the various sites. The mobile unit, known as the Transceiver Assembly (TA), consists of a radio transmitter/receiver plus a spread spectrum transmitter.

4.1.2.2 Data communication transceivers providing information to and receiving information from traffic management centers. The MobileVision TA is a two-way radio system that is capable of ancillary data and voice communications, thus satisfying this ATIS requirement. Again, the TA is performing this function as well as satisfying the Smart Vehicle and Navigation functions. Other vehicle devices either require integration to perform all functions, and/or lack reliable, complete coverage to make them effective.

4.1.2.3 Route planning and guidance systems. The MobileVision system and TA have been designed to meet the important route planning feature of ATIS. A simple menu driven program would enable a driver to select the information required, i.e., optimum route, nearest parking, road and traffic conditions, etc. The request would be sent to the MobileVision network and received by an information service provider, (i.e., MobileVision, a D.O.T. center, or an auto club), which would ascertain automatically a location of that vehicle. The requested information would then be obtained from the service provider's database and sent to the vehicle.

With nationwide and reliable urban coverage, the MobileVision system would offer ATIS that fully satisfies the IVHS requirement at a cost that would enable it to be well accepted across all levels of the marketplace.

4.1.2.4 Automated vehicle identification (AVI) for transit vehicle tracking, tolls and verification. In the MobileVision system, vehicles are instructed to transmit location "bursts" in a scheduled, controlled manner, and by this the throughput is maximized. The spread spectrum burst is modulated with a data stream which contains the unique vehicle identity number (VID) as well as other data messages. The MobileVision users' work stations, with their digitized maps and control and command software have been designed specifically for the control of fleet and transit operations. Similar to the location burst, every data message transmitted by the TA contains the VID number. Thus for transit vehicles, AVI is a standard part of every communication from a vehicle.

For tolls and verification applications there are several ways that the TA can be used. Tolls are usually associated with a checkpoint and it would be possible for the vehicle to transmit a short data message, which includes the VID. The TA has power control and thus these data transmissions could be transmitted at a low level. Using low power and directional antennas, vehicles passing through a checkpoint could react to the command.

4.1.2.5 Emergency (Mayday) services with signaling and response capabilities. One of the major features of the MobileVision system is the Emergency Roadside Service (ERS). The system uses a handheld unit with voice prompts and messages which enable a user to send a message that contains information on the VID, the problem and the location. This unit also allows the user to speak in emergencies with the operator and make a telephone call if essential. The ERS unit is very cost effective and simple to use and has been designed for the mass market.

Since ERS is a core market of MobileVision's, the human factors of the users device is currently superior to a cellular or satellite provider's handset or terminal, which were designed for different core markets. MobileVision has spent over three years running focus groups and performing research to gain this advantage.

4.1.3 Commercial Vehicle Operations ("CVO")

The MobileVision system is designed to address many areas of CVO which are described in the following paragraphs. Many of these services are possible using the MobileVision system because of the manner in which the vehicle unit has been implemented. Through the use of in-vehicle micro-controllers and a network of fixed sites, each of the following IVHS services can be implemented in a cost effective manner.[4]

Specific CVO features are:

[4]Since METS has spent almost ten years dealing with system designs for companies such as Federal Express, Ryder Truck, Consolidated Freightways, Mass Transit Authorities (i.e., Baltimore, Seattle, Omaha and Broward County), and other smaller, less known companies, the MobileVision system has effective CVO solutions as a basis. This is opposed to Cellular which has virtually always targeted and had the most success in the consumer marketplace.

4.1.3.1 Automatic Vehicle Identification (AVI) Each unit equipped with the MobileVision system carries a unique set of identifying parameters, one of which is a Vehicle Identification Number (VID). The system maintains a database of all vehicles in its purview, and makes provision for customer specific database support in workstations, i.e., customer equipment installed on premises and connected to the MobileVision network. Using a simple PC based workstation connected to the network, AVI is accomplished as part of every vehicle-to-host communication.

4.1.3.2 Automated Vehicle Classification (AVC). As discussed in the previous section, each vehicle is uniquely identified in the system. Thus vehicle classification can be accomplished on the customer's workstation using a local database. This approach provides a basic set of functionality which the user can then modify to suit their specific needs. For example, the user could make his own vehicle maintenance system based upon vehicle classification. Group calls, all calls and single vehicle calls are all accommodated by the workstation software which is already an available product.

4.1.3.3 Automated Vehicle Location (AVL). The MobileVision system provides all connected workstations with AVL information on demand or on a regular basis as specified by the user. The user then tailors his needs with the needs of the specific fleet under management.

Here MobileVision's ten years experience in the business allows MobileVision to offer superior presentation capabilities of maps, landmarks, and work areas. All of these features like the call controls mentioned above are controllable and easily modified by the user dynamically.

4.1.3.4 On Board Computer (OBC). The MobileVision mobile unit derives its flexibility from the use of an on board micro-controller. Through the use of serial interfaces, the OBC can interface to most laptop, palmtop or notebook computers, or to several standard Mobile Data Terminals (MDTs) provided by MobileVision or others. The result is a computer-to-computer link over the network to the users dispatch and business system's hub.

4.1.3.5 Two-Way Real Time Communications (TWC). The MobileVision infrastructure provides for real time ancillary two-way data and voice communications. Using a mobile data terminal or portable computer, the vehicle operator communicates with a dispatcher using either text mode, status message mode or voice mode. In addition, the vehicle operator could make emergency telephone calls from his vehicle thus promoting increased efficiency and customer satisfaction. The dispatcher could also transmit messages to the driver, receive filled-in information for delivery forms, and communicate real time re-route or special direction instructions.

4.1.3.6 Dynamic Network Routing and Scheduling. As an option, the MobileVision system provides for the incorporation of a software package called RoadRunner®. Using RoadRunner®, routes are calculated using parameters specified by the user, thus, different users can choose to optimize different parameters. For example, one user may choose to optimize delivery schedules, while another may choose to optimize pick up wait times. When performing route calculations, the system also chooses routes with the least congestion and least travel times. The user can specify these parameters in advance, or RoadRunner® can obtain traffic information through the MobileVision Network from an Information Service Provider.[5]

4.2 Advantages of MobileVision's LMS System

MobileVision's LMS Network would offer advantages in the wireless location and communications marketplace over other wireless networks, including future satellite systems. These advantages include the ability to offer bundled products and services more competitively priced, partially due to the fact that MobileVision develops its own technology and controls hardware and software modifications to the network. This provides more flexibility in avoiding technological obsolescence by incorporating new products and services as the IVHS market matures, on a timely and low cost basis.

A) Other technologies such as cellular and Specialized Mobile Radio ("SMR") are probably superior where heavy voice communication is the requirement, however, in the emerging "Intelligent Vehicle" and "Smart Highway" wireless industry, unit location is necessary to provide many of the services. Cellular and SMR competitors must add additional technology, and thus cannot be as cost effective as the MobileVision LMS system. Furthermore, not all positioning technologies added to cellular or SMR, nor satellite systems, can meet the urban coverage and location accuracy requirements necessary to provide services to markets such as Emergency Roadside Service, Stolen Vehicle Recovery and CVO. These factors limit non-LMS capabilities to produce mass market price and applications as well as the LMS solution can.

B) The cost of MobileVision's spread spectrum transmitter[6] is significantly less than the cost of a GPS or other satellite system receiver or other in-vehicle position determination systems. Therefore MobileVision can satisfy the navigation (location) function with vehicle position for a low cost to the consumer. This will increase market penetration, which is required to allow such a system to be effective.

C) One of MobileVision's advantages in providing route planning and/or guidance systems includes the fact that the in-vehicle unit is very cost effective. By utilizing voice synthesis in addition to data display, the unit would be able to provide route guidance during the journey.

---

[5]Since MobileVision designed this software and developed it internally, customizing does not require third party cost, schedule delays and inflexibility. These problems are substantial for other providers who provide only "network connectivity" and rely on others for the critical user pieces of the system.

[6]The added funtional cost of the spread spectrum transmitter to the mobile unit is in the order of $8 - $10.

5.0 ALTERNATIVE TECHNICAL SOLUTIONS FOR IVHS

As a general matter individual consumers and commercial entities purchase communications, location and security services separately. Businesses desiring DataCom services typically purchase expensive, custom implementations. DataCom will eventually migrate to trucking, fleet management, Public Safety, messengers, delivery services and vehicle tracking users. Currently, core users are workers whose jobs cause them to spend significant time in the field every day. The various techniques and combinations of technologies being used to provide position location and information services for use in integrated IVHS systems are:

5.1 Global Positioning System (GPS)

Signals received from three or more government satellites by an in-vehicle receiver are used to determine the position of the vehicle.

For a GPS-based IVHS in-vehicle system, a communications link must be added for services other than navigation. For navigation, a stand-alone GPS-based system is possible, which consists of a positioning system plus a map database. This type of system is not able to respond to real-time traffic conditions but can offer static route guidance, at a price that is relatively high because of the combined costs of the positioning system and the map terminal/display.

GPS positioning accuracy is good in open areas and when differential GPS is employed, 10-30 feet is claimed.[7] In urban canyons and densely tree covered areas GPS needs to be integrated with dead-reckoning type systems to provide suitable accuracy, since GPS is a line-of-sight technology and typically doesn't view enough satellites in major downtown environments.

In order to provide the communications link needed to meet the other IVHS requirements, it is necessary to add a cellular phone or some other two-way radio system, e.g., SMR. The vehicle installation therefore would consist of a GPS receiver, possibly a dead-reckoning system, and a radio together with the required interfaces. Two antennas would need to be installed. It should be noted that, for consumer vehicles, it is desirable that the antennas be covert or hidden as there is a noted market resistance to visible antennas. In addition, for SVR services, concealed antennas are essential to avoid easily compromising the system. GPS has countrywide coverage and cellular has virtual countrywide coverage and thus, such a combination appears to be a viable IVHS solution.

5.2 Dead Reckoning and Inertial Navigation Systems

Dead Reckoning includes compass, rate gyro and odometer(s).[8] Dead reckoning sensors determine the distance traveled, speed, heading and change of heading of a moving vehicle. Such sensors

[7]Differential techniques make use of a stationary receiver to provide corrections to measured readings from a vehicle. METS, Inc. holds a patent on the use of this technique for certain applications.

[8] Land Navigation, *Tracking the Worldwide Development of IVHS Navigation Systems*, Edward J. Krakiwsky, University of Calgary.

provide moderate accuracy over short periods of time and typically require assistance from absolute sensors, such as GPS or signposts, over longer periods.

Inertial Navigation systems require three accelerometers and three gyroscopes and are capable of high levels of relative accuracy. Because the accuracy deteriorates with time, however, they still require an input from an absolute sensor such as GPS or signposts.

When used in vehicular applications, various sensors may be employed including electronic compass, and odometers, usually differential wheel mounted types. These systems require that an absolute starting position accurately be input by some means because all subsequent position updates are derived based on the initial position estimate. Such systems suffer from a deterioration in accuracy over time, thus require periodic position inputs from an absolute position sensor.

Modern implementations of such systems used in vehicular applications use an on–board computer and digital map. The digital map is used to perform map matching so that the position can be relayed to the vehicle operator or a dispatcher in a useful manner. Because of the frequency of update required (at least once per second), the digital map must be directly accessible by the on–board computer since the necessary data communications rates would not be practical to achieve the required update rates. This virtually precludes the use of a central system to perform the necessary calculations.

Like GPS, dead reckoning and inertial navigation systems require interfacing to a cellular, SMR, or other type radio in order to satisfy most of the IVHS service objectives.

5.3 Signposts

These are small units mounted usually on the sides of streets which can transmit their position to a vehicle that comes into their proximity. Often signposts are transceivers which are capable of transmitting and receiving data to and from vehicles. Transmitted data could include traffic conditions and even a segment of a map.

These systems are satisfactory for updating locations to/from the vehicle when it is traveling on a route with signposts installed. The infrastructure requirements of signposts usually limits the use of this solution to vehicles who travel fixed routes, i.e., mass transit vehicles. Because of the limited communication capability of these systems, integration with another radio system is again required.

5.4 Other Satellite Systems

Satellite entrants in IVHS will be providing voice (Motorola's Iridium), data/location (Orbcomm), or voice/data/location (Globalstar) services to their customers. Odyssey in conjunction with cellular, will provide voice, data, location and messaging services. American Mobile Satellite Consortium, a.k.a. AMSC and Celsat will be providing dual mode cellular/satellite services. Each of these solutions could address portions of the IVHS service needs effectively, when they are deployed.

5.5 LORAN

In addition to LMS, there exists other types of terrestrial radio frequency technologies that utilize land based beacons, such as Loran-C and Omega, to provide location services. LORAN is a radio navigation system initially developed in the 1950s. It survives today, and is still used, primarily in marine and aviation navigation applications. It relies on the transmission of synchronized radio transmissions to perform position calculations using hyperbolic geometry. LORAN systems achieve moderate accuracy, however, the accuracy obtained can be improved by applying differential techniques.

LORAN operates at a frequency of 100 KHz and is subject to many man made sources of interference when used in terrestrial applications. Canyons of downtown metropolitan areas are particularly problematic and reception of LORAN signals of sufficient quality to get consistently accurate location in these areas is difficult at best. It is possible to pair the LORAN device with a dead reckoning system, however, additional cost and higher installation and integration complexity is the end result. Loran also requires integration with a radio system of some type in order to provide IVHS benefits.

6.0 COMPETITIVE OVERVIEW OF POTENTIAL IVHS TECHNOLOGIES

6.1 Cellular Telephony or SMR combined with GPS and/or Dead Reckoning

6.1.1 Cellular Telephones

Cellular telephones are available on a nearly national basis and are widely accepted as a reliable form of communication. Models can be installed (mobile) or hand held (portable). Subscribers can integrate data communications with a variety of computing devices over cellular networks. Over 16 million users currently subscribe to the service.

Cellular operators' current pricing programs are primarily designed to create revenues from a subscriber base that predominantly requires voice communications, however, prices currently restrict the volume of data traffic over analog cellular systems. The new digital cellular and cellular data standards may improve access and price over the next few years.

Cellular telephony or SMR are the current systems of choice in applications where there only exists a requirement for voice. However, in the markets of IVHS, particularly ERS, SVR, and Fleet Management, there are functional requirements of automatic vehicle location and data communications, in addition to the two-way voice service. Cellular telephony as a stand-alone technology does not meet the location requirement. Additional technology must be invented or integrated to service these markets, and with the additional associated cost, cellular providers become a higher priced solution for the mass markets. Adding GPS to cellular will cost approximately $100 to $180 dollars. Adding GPS to existing phones will cost more.

The trend for cellular is that more portable phones are being purchased rather than permanently installed phones, which creates a problem for some of the proposed services, i.e., SVR, where the reporting transceiver needs to be hidden in the vehicle. Minimum monthly fees and consumers' fears of running up high air-time fees also are mass market deterrents. Additional associated costs for mapping and an in vehicle computer to display the map, if dead reckoning is integrated, would make this an even less competitive solution. Other cost problems for cellular/GPS is that the in-vehicle installation is costly, and the majority of the population does not wish to pay for a cellular phone in the car just for emergency and IVHS services.

6.1.2 Cellular plus GPS

In adding the GPS location function to the cellular system consideration must be given as to how the function is to be handled. No "smart" CPU exists as yet in the mobile to manage the cellular/GPS activities. For instance, the location data needs to be gathered and sent to the appropriate place, or service provider. The unit must recognize a location request or know when it is to send locations e.g., in the stolen vehicle application. Mobile installed, cellular phones will need back-up batteries for ERS (i.e., dead battery). Finally, different cellular providers who compete head to head in many markets could hinder the setting up of a compatible nationwide system.

In comparing to an LMS system, the GPS based in-vehicle installation would be significantly more expensive to buy and more time consuming to install. The GPS receiver integration will take the form of an extra module. The cost of this module is $80-150 even in high quantities. In addition an extra GPS antenna is required. For GPS to be consistently reliable in urban areas, it is necessary to add a "dead-reckoning" unit to the vehicle. This is extremely important since the majority of the population and thus the largest number of emergency situations occur near or in urban areas. In addition, the majority of CVO fleet service urban rather than rural areas. It may be possible to use the ABS sensors in a "differential wheel" dead-reckoning system to improve urban accuracy, but car manufacturers might not accept any addition to these systems. The addition of a dead-reckoning unit would involve, at a minimum, sensors and a micro controller that interfaces to the GPS receiver, and could add cost in the order of $20-30. However, the bigger cost item might be the installation time.

Therefore the addition of a GPS navigation system to a cellular mobile phone would cost at least $100-180 plus installation time. Current solutions sell in the $2,000 to $2,500 dollar range, and would not be cost competitive for the mass markets.

In order to satisfy the ERS, Stolen Vehicle Recovery, and Automobile Alarm requirements, additional interfaces to the cellular radio portion of the installation are required together with new handset units designed for easier ERS use. Using a cellular phone as the communications link could present certain battery consumption problems especially associated with the stolen car service where the unit must be left on when the vehicle is unattended for extended periods.

As mentioned earlier, it is important to consider that the cellular marketplace is evolving to a portable one, rather than in-vehicle installed handsets. If the portable cellular phone is taken by the user into his/her destination, there is no communication link for SVR signaling. If a second permanent installed phone is used, the consumer must pay extra to acquire the portable handset which the market seems to prefer.

6.1.3 Cellular plus Dead Reckoning

Cellular or SMR Systems which use dead reckoning as their core location technology may achieve moderately accurate results. However, accuracy degrades with time thus requiring an on-board device (or some other means) to obtain absolute position updates. This approach is not very cost effective since to obtain good accuracy some form of map storage device is required in the vehicle along with an absolute position sensor of some sort; e.g., GPS, LORAN or signposts. Current solutions sell in the $2,000 to 2,500 dollar range, and would not be cost competitive for the mass markets.

6.1.4 SMR

SMR businesses will also compete in the IVHS markets. However, the same location functionality requirement of adding other technologies will be required for SMR operators. Here again, to offer a competing service outside of predominately voice and data markets, will produce a combination SMR/GPS and/or dead reckoning.

6.1.5 Competitive Summary

Cellular or SMR combined with GPS and/or dead reckoning have the following advantages and disadvantages:

1. <u>Advantages</u>

    - Universal coverage;
    - Proven systems;

- In-vehicle navigation systems, by which the vehicle can independently determine its location.

2. Disadvantages

- Need for integration of two or three technologies;
- Additional costs due to integration and duplicative equipment, such as antennas;
- Cellular phones are migrating more to portable versus installed, and users want to carry them, not leave them in the car;
- GPS not reliable for urban location accuracy;
- Integration of GPS may require change out of 16 million phones already in service;
- Service providers for monitoring services must be cultivated;
- New phone handsets tailored for ERS necessary to meet IVHS requirement for user friendly human factors.

6.2 Satellite Systems

Low-Earth orbit ("LEO"), medium-Earth orbit ("MEO"), and geosynchronous-Earth orbit ("GEO") satellites will come into operation over the next five years providing various combinations of voice, data, and location services.

LEO entrants will be providing voice (Motorola's Iridium), data/location (Orbcomm), or voice/data/location (Globalstar) services to their customers. MEO entrants (Odyssey) in conjunction with cellular, will provide voice, data, location and messaging services. GEO entrants American Mobile Satellite Consortium and Celsat will be providing dual mode cellular/satellite services. These systems were designed as worldwide or nationwide solutions, but suffer obstacles when marketed to a user with a more localized objective, such as a typical consumer or a local CVO operation.

The major obstacles satellite services must overcome (when deployed and activated), are: (1) the equipment costs and per minute/monthly fees being advertised are more expensive than other solutions, (2) the location accuracy (typically averaging 1,000 feet to 2/3 mile) is not sufficient to be utilized in urban environments where the majority of emergency and fleet management services are provided, and (3) many of the satellite systems will be targeted at only one or two of the required IVHS functionalities rather than all of them. There are also going to be short periods when a satellite is not in "view" of the user, and/or a satellite goes "dead" and a spare must be launched or repositioned to provide complete coverage. Finally although pre-marketing of services often promises competitive costs, actual installation, equipment and monthly costs must be priced to provide a return on investment. Since either the satellites or earth stations are expensive, overhead costs such as these along with active spare redundancy, launching costs, etc., create a significant overhead that must be recouped.

A summary of satellite systems' IVHS advantages and disadvantages:

1. Advantages

- Universal coverage.

2. Disadvantages

- For location accuracy, could be significant liability for emergency and CVO markets;
- Relatively high per minute/monthly fees;
- Other than AMSC, not yet available/deployed; some not planned to be operational for up to 6 years;
- Many will not provide voice, data and location;
- Expensive earth stations and/or satellites, redundancy, spare "birds" and launch costs cause high overhead costs;
- Spares for backup either required to be fully redundant, or system will suffer from what could be significant downtime after failures.

7.0 DISCUSSION

In the emerging IVHS industry where location information plays a dominant role, MobileVision believes its LMS communications network is the most comprehensive and competitive system that exists today. MobileVision's system provides the features and services at the required level of costs to satisfy the major target objectives of IVHS.

MobileVision's technology developed for its system can provide vehicle location, ancillary data communications, and ancillary two-way voice communications from a *single* radio unit. Competing technologies such as cellular providers and Specialized Mobile Radio operators compete favorably with LMS in applications where voice communications dominate. However, in the "Intelligent Vehicle" and "Smart Highway" wireless arena where location is necessary , these competitors must add additional technology. With the resultant additional costs, they are not as cost competitive to the mass markets.

Furthermore, complimentary technologies added to cellular or SMR or alternatives offered by satellite providers, do not meet the basic coverage and location accuracy requirements necessary to provide services for emergency or CVO markets in urban areas. This is because non-LMS solutions are not consistently reliable or accurate enough for urban deployment, where the primary demand for most emergency and commercial services is concentrated. For instance, accidents which trigger an airbag activation, car jackings, abductions, and heart attacks, happen much more commonly in or near urban environments as compared to rural areas. Likewise, local and regional couriers, delivery services, transportation and other service providers, outnumber the over the road trucking market and spend the majority of their time on urban thoroughfares, not interstate highways.

For these reasons it is clear that the MobileVision LMS system currently offers particular advantages, for IVHS markets, especially for mass market applications.

Interference Analysis of Part 15 Devices and LMS Wideband Systems

INITIAL CALCULATIONS

G K Smith

March 8th, 1994

DRAFT

METS, Inc.

Summary

Summary of Conclusions

Interference between Part 15 and wideband LMS systems in the 902 to 928 MHz band will be isolated. Interference between 'indoor' Part 15 devices and wideband LMS is unlikely and simply averted. Interference between 'outdoor' Part 15 devices and wideband LMS is more likely but can be easily corrected by sensible co-operation. Correct use of transmitted power level and directional antennas will prevent interference in the majority of cases, and if the Part 15 device center frequency is set to the center of the band (915 MHz), there would be no problems.

The potential interference problems arise when the Part 15 devices are transmitting at the highest allowable power and/or when the link distance is long. When the link distances are short, the transmitted power could be less. In the cases where full power is needed, then the use of directional antennas or selection of the center frequency band should prevent interference problems with the LMS systems.

Summary of Paper

In the 902 to 928 MHz band unlicenced, "Part 15", radio devices are allowed to operate on a non-interfering basis. In general the devices operate persuant to the rules of section 15.249 which limits the transmission to 50mv/m @ 3m.(equivalent to 0.75mW ERP) or persuant to section 15.247, where using spread spectrum , the transmitted power can be 1W.

This paper divides the Part 15 radio devices into two basic types:

outdoor devices	- e.g. radio modems, regional data networks, mobile telemetry and data collection.
indoor devices	- e.g. cordless phones, anti-theft devices, wireless LANs.

The intention of this paper is to carry out simple calculations in order to assess the level of the interference between LMS systems and both types of Part 15 devices, and to make recommendations in the light of the results.

Propagation calculations are shown and the interference assessed between LMS systems (mobiles and fixed sites), and indoor and outdoor Part 15 devices.

Assuming that the two systems are operating in the same frequency band, the results show that:

a) With respect to interference between LMS systems and Indoor Part 15 devices

-There is a possibility that indoor Part 15.247 devices, transmitting 1W, operating within a mile of a wideband LMS fixed site, will desensitize that site by 20dB, effectively reducing its range by 3 times.

-Indoor Part 15.249 devices, would need to be within a third of a mile in order to cause the same effect.

-There is negligible interference from the indoor Part 15 radio to the LMS mobiles.

-There is low probability of interference to the indoor Part 15 radio from wideband LMS mobiles.

-Indoor Part 15 devices could experience interference from the LMS forward links and narrow band data/voice signals if a transmitting LMS fixed site is within half a mile.

-If the operating distance of the indoor Part 15 device is kept short, then the chance of interference is very low, as the operating distance increases, then the chance increases.

b) With respect to interference between LMS systems and Outdoor Part 15 devices

-There will be significant blocking of an LMS fixed site by outdoor Part 15 radio if it is transmitting at 1W and there is no antenna directivity, With a 20 dB less signal (due to directional antennas or less power), the outdoor Part 15 radio would have to be over a mile away from the fixed site to avoid blocking.

-An LMS mobile within about quarter mile of an outdoor Part 15 1W transmitter will be unable to receive narrow band data or voice.

-There is a very good possibility of an LMS mobile interfering with the reception of an outdoor Part 15 radio, depending on the Part 15 link distance. For a link distance of 1 mile, a mobile within 0.8 miles has the capability to interfere.

-An LMS transmitting site will severely interfere with the outdoor Part 15 link.

-The outdoor Part 15 radios and the LMS system do have the capability of interfering with each other but it is simply overcome if the outdoor Part 15 devices use the center of the band.

c) With respect to mutual interference between Part 15 devices:

-The interference from an outdoor Part 15 transmitter on another outdoor Part 15 receiver is slightly worse than the interference from an LMS mobile. The use of directional antennas should be able to overcome most problems.

-Indoor Part 15.249 devices could experience interference from outdoor Part 15 devices, depending on the link distance. The interference potential is higher than that from the LMS mobiles, and other indoor Part 15 radios.

-Indoor Part 15.247 radios could interfere with outdoor Part 15 links if they are within a quarter mile of each other but in practice there is little possibility.

As the major interference is with the outdoor Part 15 devices, a further analysis is carried out into the typical interference rejection and selectivity of these devices. It is shown that the outdoor Part 15 device typically has a jamming margin of 0dB and hence a poor basic interference rejection. A comparison is made between conventional radio and spread spectrum links which concludes that in any given area, for a data rate of 64 kbps, it is possible to have 20 times more conventional than direct sequence spread spectrum radio links. It is pointed out that the 2400MHz band offers much more bandwidth and thus number of channels in addition to presenting the opportunity to design spread spectrum radios with useful jamming margin.

The use of some of the outdoor Part 15 devices and the poor jamming margin brings to question whether these type of devices fall under the original definition for Part 15, i.e. "low power, limited range devices".

Recommendations

Based on the analysis, the following Recommendations are made:

1 - Part 15.247 radios should be able to be simply set to channels in the center of the band i.e.912-918MHz.

2 - When intended for long distance links, the Part 15.247 device should be encouraged onto the 2400 and 5800 MHz bands where there is more usable bandwidth and there is the potential for designing devices with reasonable jamming margin.

3 - The installation manuals for Part 15.247 devices should include a section that tells the user the device is liable to interference and/or liable to cause interference if an LMS system is operating in their area and that, as a first choice, channels in the center of the band should be selected.

4 - Recommended power levels and the correct use of directional antennas, for specific link distances, should be included in the installation manuals for Part 15.247 devices.

5 - Part 15.249 devices should not need any specific recommendations.

6 - Wideband LMS systems should be designed to accept a certain degree of desensitization from Part 15 devices.

7 - Part 15 manufacturers and users should co-operate to find the simplest method of overcoming any interference, such that both systems are operable.

1. Part 15 Specifications

In the 902 to 928 MHz band unlicensed, "Part 15", radio devices are permitted to operate on a non-interfering basis. In general the devices operate according to the rules of Section 15.249 which limit the transmission field strength to 50mv/m @ 3m, which is equivalent to 0.75mW ERP (from an isotropic antenna). In addition, devices using spread spectrum techniques operate under Section 15.247, which has the following basic specifications:

Transmitted power		1W peak output power.
		6dBW max ERP, with directional antenna.
- Direct sequence spread spectrum		
	Transmitted power	<8dBm in any 3kHz bandwidth
	Processing Gain	>10dB
	Minimum bandwidth	500kHz @ 6dB
- Frequency hopping		
	No. of hopping frequencies	50 minimum
	Max B/W of hopping channel	500kHz @ 20dB
	Channel occupancy	<0.4 secs. within 20 sec period

2. Part 15 Radio Devices

This paper divides the Part 15 radio devices into two basic types:

Outdoor devices	- e.g. radio modems, regional data networks, mobile telemetry and data collection.
Indoor devices	- e.g. cordless phones, anti-theft devices, wireless LANs.

The intention of this paper is to carry out simple calculations in order to assess the level of the interefernce between LMS systems and Part 15 devices. Therefore typical cases are assumed rather than the complete range of possibilities. For example, the outdoor Part 15 radios have been modeled as roof top transmitters at a nominal height of 30 feet, and the indoor Part 15 radios as ground level transmitters at a nominal height of 6 feet, with one building wall to the outside.

3. Propagation model

Throughout this paper, the 'Egli'[1] propagation formula is used. Namely:

$Lt = 85.9 + 20 \log F + 40 \log D - 20 \log hb - 20 \log hm$	F in MHz D in kms hm & hb in meters hm < 10 m (mobile)

This formula can be re-written as:

$Lt = 114.7 + 20 \log F - 20 \log hb.hm + 40 \log D$	F in MHz D in miles hm & hb in feet

[1]J.J.Egli, "Radio propagation above 40Mc over irregular terrain", Proc. IRE, vol. 45, no 10, pp. 1383-1391, Oct. 1957. This simple formula used for suburban propagation loss, gives results that agree very closely with the CCIR Okumura method and also with the Hata formulas (which are derived from the Okumura measurements). It is a well known formula used by radio engineers.

4. *Desensitization and Range reduction of LMS mobile*

From standard definitions, the thermal noise is -174dBm/Hz.

For a 2Mbps direct sequence spread spectrum the main lobe bandwidth is 4 MHz.

In 4 MHz bandwidth the thermal noise is -108dBm. Assuming a noise figure of 6 dB, the noise floor will be -102dBm.

Desensitization occurs when the 'noise' floor is raised by interference. In a direct sequence spread spectrum receiver, any un-correlated interfering signal becomes 'noise' by the action of de-correlation. Thus, the received power of an interfering signal can be considered as adding to the noise at the receiver front end. The effective noise at the receiver front end is thermal noise plus the noise figure. In the above example, this is -102dBm.

Therefore, an interfering signal received at a level of -92 dBm would effectively desensitize the receiver by 10 dB, and an interfering signal received at a level of -82 dBm would effectively desensitize the receiver by 20 dB

The propagation loss due to distance is "40 log D", thus a 10 dB desensitization is equivalent to reducing the range by a factor of $10^{10/40} = 1.78$.

A table of desensitization and range reduction factors is given in Table 1.

Table 1- Range reduction with desensitization

Interference level, dBm	-102	-92	-82	-72	-62
Desensitization, dB	0	10	20	30	40
Range reduction factor	1	1.78	3.16	5.6	10

Thus, based on Table 1, an interfering signal 20 dB above the 'noise' will reduce the range by a factor of 3. This corresponds to a received level of -82dBm.

5. *Indoor Part 15 Radio interference.*

5.1. Penetration loss due to building

Work carried out on the radio coverage in buildings[2] has shown a floor attenuation factor, f, at 864 MHz, in a building as

$5.5\text{dB} < f < 15 \text{ dB}$ or $f = 10$ dB with a standard deviation of 5 dB.

CCIR Report 567-2[3] gives a similar figure, for typical steel and concrete and stone office buildings, of 10dB with a standard deviation of 7.3 dB. Severe cases, with steel shell buildings resulted in 28.5 dB mean.

Therefore, for the purposes of this paper, a figure of 10dB is used for the penetration loss due to a building wall.

[2]Cordless Telecommunications in Europe, Wally Tuttlebee (Ed.), Springer-Verlag, Chapter 7, 'The Radio Channel", page 159.
[3]CCIR Report 567-2 "Methods and Statistics for Estimating Field Strength Values in the Land Mobile Services using the Frequency Range 30MHz to 1 GHz".(1978-1982), clause 5.3. "Building penetration loss". Measurements carried out in Louisville, Kentucky.

5.2. **Indoor Part 15 device desensitizing the LMS fixed site receiver.**

If the transmitted power of the indoor Part 15 radio is 1W, (30dBm), then due to the 10 dB loss though the building wall, the effective radiated power can be considered as 20dBm. The required distances of the Part 15 radio from the LMS fixed site, for 0, 10 and 20 dB desensitization ("Threshold" -102, -92 and -82 dBm respectively), can be calculated. Table 2 shows the results:

Table 2 - Indoor Pt 15 radio interference distances

Using Egli formula

(assuming 9dBi antenna at fixed site)

Threshold	**-102**	-102	-102	**-102**	-102	dBm
Pt (ERP)=	**20**	10	0	**-10**	-20	dBm
hb=	**200**	200	200	**200**	200	ft
hm=	**6**	6	6	**6**	6	ft
R=	**2.89**	1.62	0.91	**0.51**	0.29	miles
Threshold	**-92**	-92	-92	**-92**	-92	dBm
Pt (ERP)=	**20**	10	0	**-10**	-20	dBm
hb=	**200**	200	200	**200**	200	ft
hm=	**6**	6	6	**6**	6	ft
R=	**1.62**	0.91	0.51	**0.29**	0.16	miles
Threshold	**-82**	-82	-82	**-82**	-82	dBm
Pt (ERP)=	**20**	10	0	**-10**	-20	dBm
hb=	**200**	200	200	**200**	200	ft
hm=	**6**	6	6	**6**	6	ft
R=	**0.91**	0.51	0.29	**0.16**	0.09	miles

If the indoor device is transmitting 1W (Section 15.247), within the bandwidth of the spread spectrum signal, 20 dB desensitization of the fixed site is possible if the indoor Part 15 radio is within 0.9 mile of the site. If the device is transmitting 1mW (Section 15.249), then it needs to be much closer, 0.16 mile, to desensitize the fixed site by 20 dB.

The figures in Table 2 are worst case calculations and, other losses, such as antenna efficiency and blocking, could be present. However, the clear conclusion is that indoor Part 15.247 radios could cause a 10 to 20 dB desensitization of the LMS fixed site if they are within 1 mile of the LMS site.

Summary

Required distance of Indoor Part 15 from LMS fixed site for 0, 10 and 20 dB desensitization.

Desensitization	0dB	10dB	20dB
Part 15.247	2.9	1.6	0.9 miles
Part 15.249	0.5	0.3	0.2 miles